# Probing proton spin structure via heavy flavor production in PHENIX

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**Abstract.** The measurement of spin asymmetries in polarized p+p collisions provides an opportunity to probe the spin structure of nucleons. With transversely and longitudinally polarized proton beams at RHIC, we can measure both double longitudinal spin asymmetry $A_{LL}$ and single transverse spin asymmetry $A_N$. At RHIC energy, heavy quark (charm and beauty) production is dominated by gluon-gluon interactions, so measurements of $A_{LL}$ and $A_N$ will allow us to directly probe the polarized gluon distribution and gluon's Sivers functions, respectively.

PHENIX experiment collected 3.5 pb$^{-1}$ (beam polarization $\sim$ 50%) and 10pb$^{-1}$ (beam polarization $\sim$ 60%) data from year 2005 and 2006 runs respectively. In this analysis, the J/$\Psi$ have been measured through the J/$\Psi \rightarrow \mu^+\mu^-$ channel at forward rapidities, and about 30,000 J/$\Psi$ candidates are reconstructed from Lvl2 triggered data production. We present the latest results of J/$\Psi$ $A_{LL}$ and $A_N$ measurements at forward rapidities from the PHENIX experiment.

## 1. Introduction:

### *1.1. Longitudinal Polarized Double Spin Asymmetry $A_{LL}$*

The quark contribution to the proton spin was found to be small by the European Muon Collaboration (EMC) with polarized lepton-nucleon deep inelastic scattering (DIS)[1]. Since then, a large number of DIS experiments have established that only 10 $\sim$ 30% of the proton spin is carried by the quarks and anti-quarks, which is smaller than the naive quark parton model expectation. The rest of spin must be coming from the gluon spin and the parton orbital angular momentum. Since gluons are charged neutral and do not couple to virtual photons in the leading order, the polarized gluon distribution, $\Delta g(x)$, is not well constrained by the DIS experiments. With RHIC, we can collide quarks and gluons at high energy. Furthermore, heavy quark production in polarized p+p collision at RHIC energy is dominated by the gluon-gluon interaction, thus providing direct access to the (polarized) gluon distribution in the proton. The double longitudinal spin asymmetry in heavy quark(onium) production can be written as

$$A_{LL}^{Q\bar{Q}} \sim \frac{\Delta g(x_1)}{g(x_1)} \times \frac{\Delta g(x_2)}{g(x_2)} \times \hat{a}_{LL}^{Q\bar{Q}} \tag{1}$$

where $g(x)$ ($\Delta g(x)$) is the unpolarized (polarized) gluon distribution function and $\hat{a}_{LL}^{Q\bar{Q}}$ is the double spin asymmetry for the partonic subprocess $g+g \rightarrow Q\bar{Q}(Q = c$ or $b)$, and has been estimated to be $\sim O(0.1)$ in pQCD calculations[2, 3, 4].

### *1.2. Transverse Polarized Single Spin Asymmetry $A_N$*

The measurement of single transverse spin asymmetries gives us an opportunity to probe the quark and gluon structure of transversely polarized nucleons. Large transverse single spin asymmetries of up to $20\% - 40\%$ were observed for pions produced at large $x_F$ at $\sqrt{s} = 20$ GeV[5] and have been found to persist at $\sqrt{s} = 200$ GeV by the STAR [6] and BRAHMS[7] experiments, although they were expected to vanish in pQCD calculations at the leading order. A number of pQCD based models have been developed to explain this phenomena. Among them are the Sivers effect (transversely asymmetric $k_T$ quark and gluon distributions)[8], the Collins effect (transversity distribution in conjunction with spin-dependent fragmentation function)[9], and the higher twist effect (interference between quark and gluon fields in the initial or final state)[10, 11].

At RHIC energies, heavy flavor production is dominated by the gluon-gluon interaction; thus Collins effect has minimum impact on $A_N$ as the gluon transversity is zero. Therefore, the production of heavy flavor particles in transversely polarized p+p collisions at the PHENIX experiment offers a good opportunity to probe the gluon Sivers effect.

## 2. PHENIX Experiment

The PHENIX detector consists of global detectors at very large pseudo-rapidity and four spectrometers. A pair of beam-beam counters(BBC) that cover the pseudo-rapidity range $3 < |\eta| < 4$ have been used for the minimum bias trigger as well as for the relative luminosity measurement. Two central arm spectrometers have a range $-0.35 < \eta < 0.35$ in pseudo-rapidity, azimuthal angle coverage of 180 degrees, and have been used to measure charged particles and photons. The two muon spectrometers in the forward and backward directions measure high energy muons in pseudo-rapidity $1.2 < |\eta| < 2.4$ and cover full azimuthal angle. This allows PHENIX to do a wide range of measurements using different probes including pions, electrons, muons, prompt photons and jets. The results presented here are from measurements with the muon spectrometers.

## 3. Experimental Results

In this report we present the latest results of double longitudinal spin asymmetry and single transverse spin asymmetry measurements in J/$\Psi$ production in polarized p+p collisions at RHIC. The PHENIX muon spectrometers have measured J/$\Psi$ yields through the J/$\Psi \rightarrow \mu^+\mu^-$ channel at forward rapidities ($1.2 < |\eta| < 2.4$). During the recent 2005 and 2006 polarized pp run, the PHENIX experiment ran a special Lvl2

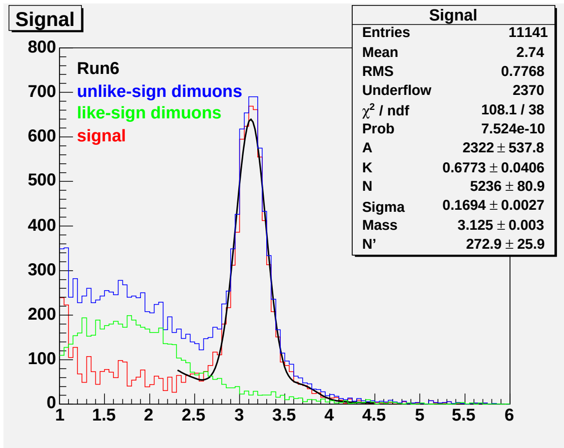


**Figure 1.** Dimuon invariant mass distribution.

trigger filtering program for the fast online data production. The results presented here are come from this data sample.

The J/Ψ yield is obtained by fitting the dimuon mass spectrum with a single exponential background plus two gaussian functions (for J/Ψ and Ψ′) in the mass range 2.3 GeV - 4.5 GeV (as shown in figure 1, use transverse data as an example). The Monto Carlo simulation shows the systematic error in determining the J/Ψ yield from the fit is less than 2%.

### *3.1. Definition of $A_{LL}$ and $A_N$*

The double longitudinal spin asymmetry is defined as

$$A_{LL} = \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}}, \quad R = \frac{L^{++}}{L^{+-}} \tag{2}$$

The inclusive $A_{LL}^{incl}$ is given by,

$$A_{LL}^{incl} = \frac{1}{P_B \cdot P_Y} \frac{N^{++} - R \cdot N^{+-}}{N^{++} + R \cdot N^{+-}} \tag{3}$$

where $\sigma_{++}(\sigma_{+-})$ is the cross section with same(opposite) helicity, $N^{++}(N^{+-})$ is the number of oppositely charged dimuon pairs within two sigma $J/\psi$ mass window in the same (opposite) helicity state p+p collisions, and $P_B$ and $P_Y$ are the beam polarizations, and R is the relative luminosity$\frac{L^{++}}{L^{+-}}$. R is determined with BBC detectors from the minimum biased trigger.

The transverse single spin asymmetry $A_N$ can be determined by:

$$A_N = \frac{1}{P_b} \frac{\sigma^{\uparrow} - \sigma^{\downarrow}}{\sigma^{\uparrow} + \sigma^{\downarrow}} = \frac{1}{P_b} \frac{N^{\uparrow} - RN^{\downarrow}}{N^{\uparrow} + RN^{\downarrow}}, \tag{4}$$

Alternatively, we also use square root formula

$$A_N = \frac{1}{P_b} \frac{\sqrt{N_L^{\uparrow} \cdot N_R^{\downarrow}} - \sqrt{N_L^{\downarrow} \cdot N_R^{\uparrow}}}{\sqrt{N_L^{\uparrow} \cdot N_R^{\downarrow}} + \sqrt{N_L^{\downarrow} \cdot N_R^{\uparrow}}}, \tag{5}$$

to cross check our results.

The asymmetry of J/Ψ was determined for each fill using Eq. (4), then averaged over all fills.

The raw J/Ψ sample is contaminated by other background, mainly coming from the Drell-Yan process, open charm and light hadron decays. The $A_{LL(N)}^{J/\Psi}$ was corrected for the contribution of background by using

$$A_{LL(N)}^{J/\psi} = \frac{A_{LL(N)}^{incl} - r \cdot A_{LL(N)}^{BG}}{1 - r} \tag{6}$$

and

$$\delta A_{LL(N)}^{J/\psi} = \frac{\sqrt{(\delta A_{LL(N)}^{incl})^2 + r^2 \cdot (\delta A_{LL(N)}^{BG})^2}}{1 - r} \tag{7}$$

where $r \approx 12\%$ is the background fraction under $J/\psi$ mass peak and $A_{LL(N)}^{BG}$ is the averaged background asymmetry. $A_{LL(N)}^{BG}$ is obtained from the like and unlike sign dimuon pairs within $2.0GeV < M_{\mu\mu} < 2.5GeV$, and like sign muon pairs within $2.8GeV < M_{\mu\mu} < 3.5GeV$, see Figure 1.

The systematic uncertainty from bunch to bunch and fill by fill has been checked with bunch shuffling technique with randomly assigned polarization direction for bunches in each fill. The bunch-to-bunch and fill-to-fill systematic errors are negligible compare with the statistical uncertainty for both the 2005 and 2006 runs.

### *3.2. $A_{LL}$ Result*

The double longitudinal spin asymmetry is calculated for two $p_T$ bins. Figure 2 shows the preliminary $A_{LL}^{J/\psi}$ results at two $p_T$ bins, $0.82GeV$ and $2.3GeV$, respectively, along with the theoretical model calculations[3, 4] with several different polarized parton distributions and $J/\psi$ production models. It is interesting to note[4] that $A_{LL}^{J/\Psi}$ is sensitive to various polarized gluon distributions but not to the actual production mechanism at high $p_T$.

### *3.3. $A_N$ Result*

The single transverse spin asymmetry was calculated for two $x_F$ bins. Figure 3 shows the preliminary result of the single spin asymmetry as a function of $x_F$ in J/Ψ production from the 2006 RHIC transverse run. A scale uncertainty of 20% due to the absolute polarization values is not included in this analysis. Within the limits of errors, $A_N$ is consistent with zero over the measured $x_F$ range.

Currently there is no theoretical calculation of J/Ψ's $A_N$. However, there is a prediction of maximum values of $|A_N|$ in D meson production at fixed transverse momentum $p_T = 1.5$ GeV/c at the RHIC energy, as shown in figure 4[12]. The solid line shows $|A_N|_{max}$ when the gluon Sivers function is set to its maximum with the quark Sivers function set to zero, and the dashed line corresponds to a maximized quark Sivers function with the gluon Sivers function set to zero. If the transverse single spin

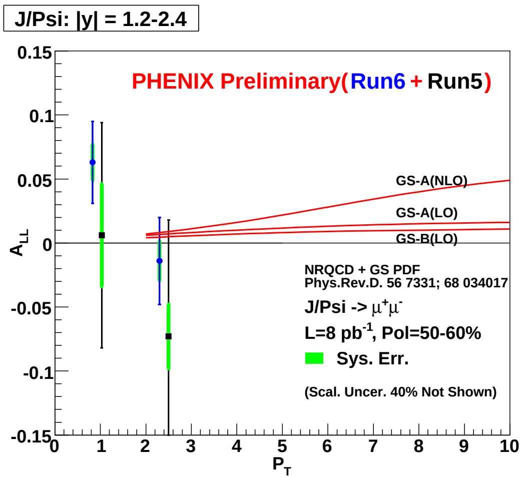


**Figure 2.** PHENIX preliminary results on double spin asymmetry vs $p_T$ in $J/\Psi$ production. Theoretical calculations are also shown for comparison with the data

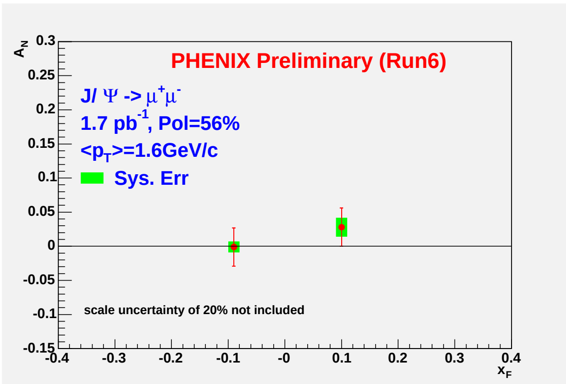


**Figure 3.** Transverse single spin asymmetry vs. $x_F$ for J/$\Psi$ at forward rapidities.

asymmetry comes from the initial state (the J/$\Psi$ production mechanism does not play an important role), then we expect $A_N$ in J/$\Psi$ and D meson production to be similar. The fact that there is no sizable asymmetry observed in figure 3 may indicate our results disfavor the maximum contribution of gluon's Sivers function.

## 4. Summary and Outlook

The longitudinal double spin asymmetry in $J/\Psi$ production has been measured at $\sqrt{s} = 200$ GeV at RHIC. The latest Run6 results have shown a factor of 8 improvement over Run5 in terms of the Figure of Merit (FOM) $P^4L$. However, the results are still statistically limited to distinguish various gluon polarization models. Besides the $J/\Psi$ measurement, we are also studying $A_{LL}$ in open charm production which potentially has $\sim 10^2$ more statistics than $J/\Psi$. Analyses are underway and preliminary results are expected soon from recently finished Run5 data production.

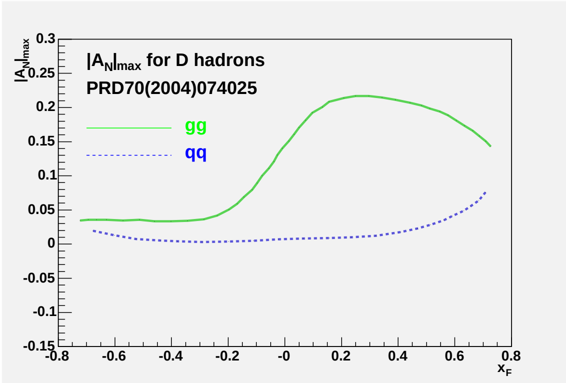


**Figure 4.** Maximized values of $|A_N|$ for the process p+p→DX as a function of $x_F$ at fixed transverse momentum $p_T = 1.5$ GeV/c at RHIC energy.

In the future with significantly improved luminosity and polarization of 70% (about a factor of 15 improvement in FOM compared to Run6), we expect to provide precise determination of the contribution of the gluon polarization to the proton spin through heavy quarks as well as other channels. In addition to $\Delta g(x)$, with the future runs, we will also measure the flavor identified quark and antiquark polarization $\Delta u(x), \Delta\bar{u}(x), \Delta d(x), \Delta\bar{d}(x)$ via $W^{\pm} \to \mu^{\pm} + \nu$ channel. It is expected that RHIC-SPIN will provide key inputs toward the resolution of the "spin crisis".

The transverse single spin asymmetry $A_N$ for J/Ψ has been measured for the first time at forward rapidity and $\sqrt{s} = 200$ GeV with the PHENIX muon spectrometers. Using Level-2 dimuon triggered data sample (corresponds to 60% of the whole 2006 transverse data set), no sizable $A_N$ of J/Ψ has been observed which indicates our results disfavor the maximum gluon Sivers contribution.

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